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IPPW 2006

Extreme Temperature/Radiation Tolerant Crystal Oscillator for High Reliability & Space Applications

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Extreme Temperature Frequency Control

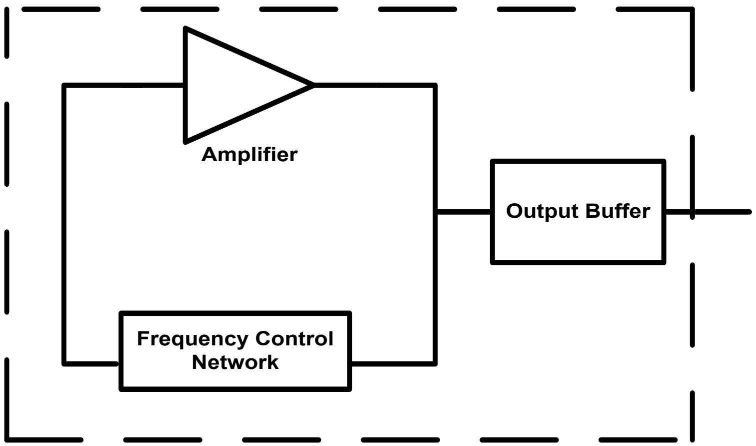
- **Working on technologies that serve**
  - **Missions to Venus**
    - Extreme high temperature to 460~470 ºC
    - High pressure to 90 bar
    - Shock and vibration
    - Total dose exposure
  - **Missions to Mars and Moon**
    - Extreme low temperatures to -180 ~ - 200ºC
    - Large number of thermal cycles (≥ 1500)
    - Shock and vibration
    - Total dosage exposure
- **Solutions for the above have significant synergy with**
  - **Oil and gas exploration, geothermal well operation and instrumentation used in nuclear reactor environment**
    - High temperature to 350 ºC
    - High pressure to 1500 bar
    - High shock and vibration
    - Thermal cycles ≥ 100
    - Very long operating life under the combined effects of the extreme environment
- **FMI has its activities focused on solving the problems in these areas and to deliver better solutions for other typical high reliability and space applications**

NASA SBIR II Project Objectives

- Development of integrated crystal oscillator solutions for
  1. Extreme low operating temperature from -180ºC to + 125ºC
     - Miniaturized, very small outline, low profile
     - Surface mountable
     - Radiation tolerant
  2. Extreme high operating temperature from -55ºC to + 460ºC
     - High ambient pressure (90 Bar)
     - Radiation tolerant
     - Surface mount

Other Attributes

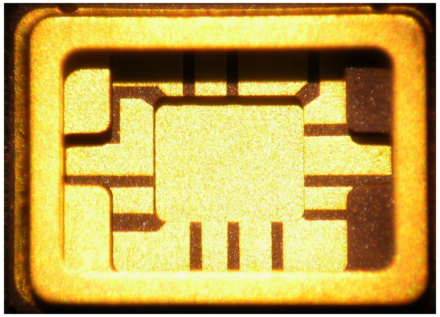
- Both solution needs to be rugged, scalable, and commercially available to be used in space applications and other demanding requirements such as down-hole and geothermal instruments
- In either case, the areas to address are:
  - package definition
  - Resonator design
  - Active device (crystal driver)
  - Interconnect scheme
  - Integration/fabrication
  - Testing



Simplified Oscillator Block Diagram

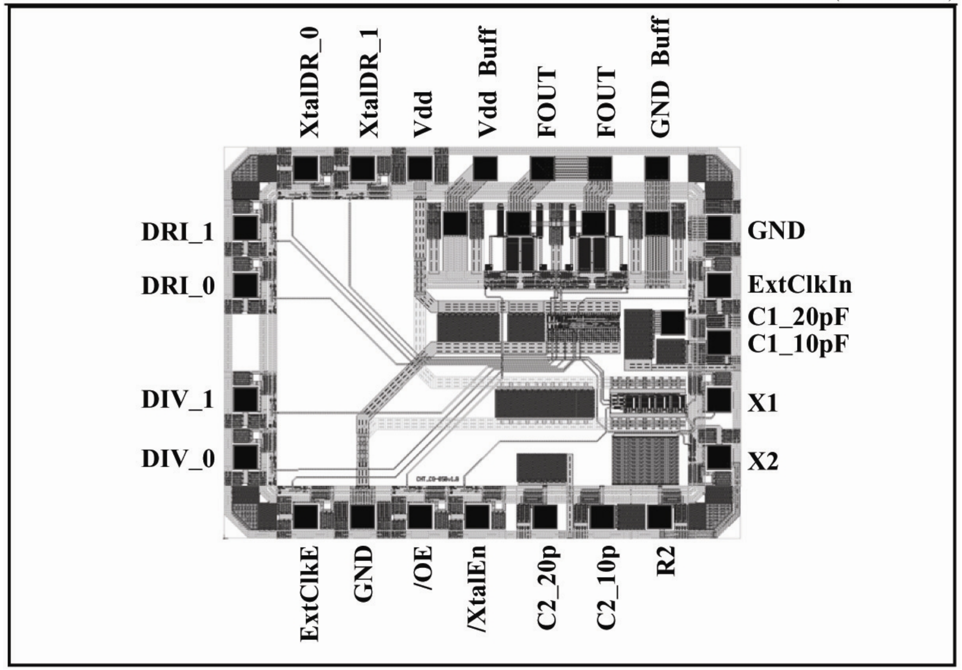
Miniature 5X7mm Ceramic Package

- Industry standard size 5 x 7 mm
- Same size package for
  Crystal oscillator or resonator only
- Same oscillator housing to allow for different IC integration to handle different temperature ranges
- Adaptable for very high shock applications
- Address both the space applications and high temperature requirements to 200ºC
- Multi-conductors layer structure



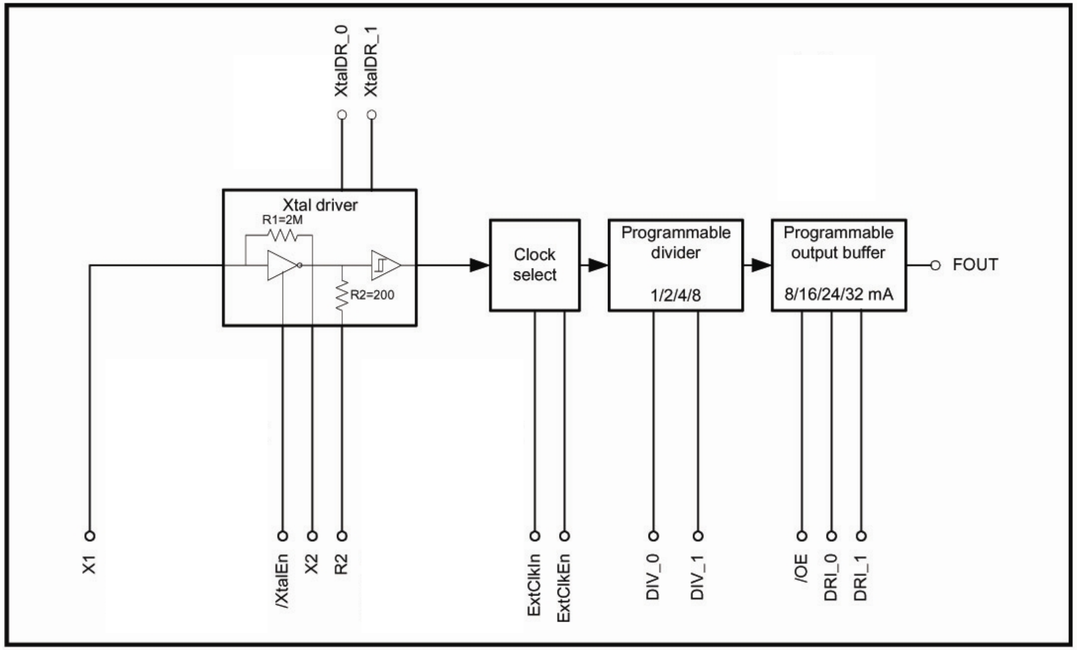
Extreme Low Temperature Design Approach

- **Single IC solution**
  - SOI technology for radiation tolerance and stable performance over wide temperature range
  - Resonator drive level options for various crystal frequencies
  - Provisions to reach low output frequencies and in-circuit automatic testing
  - Dimensional fit to the package size



Extreme Low Temperature Design Methodology

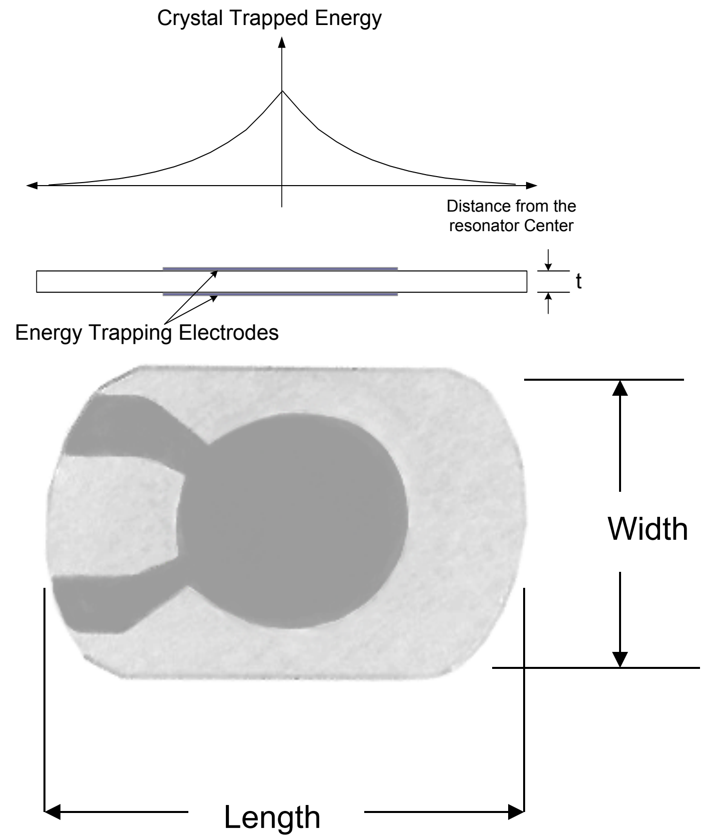
- **Oscillator IC**
  - Implemented based on the Pierce configuration
  - Fabricated on X-Fab SOI process
  - Die size of 85x65 mils fits well in the package cavity
  - Sample ICs were separately tested for 1000 hours at 125°C as a reference point
  - Single IC→ better reliability for existing applications
  - In 5X7 SMD, reduces foot-print by 7 times compared to standard flat-packs
  - Can be used with larger packages as well



IC Block Diagram

Extreme Low Temperature Design Approach

- **Resonator Design**
  - Blank dimensions optimized to avoid residual trapped energy at the edge
  - Wide frequency range from 8MHz to 50+ MHz on the fundamental mode
  - Higher frequencies from 30 MHz to 110 MHz on the 3rd overtone mode
  - Very high Q quartz bar material, with excellent surface smoothness
  - Can be fabricated in small or large volume



Approximate shape

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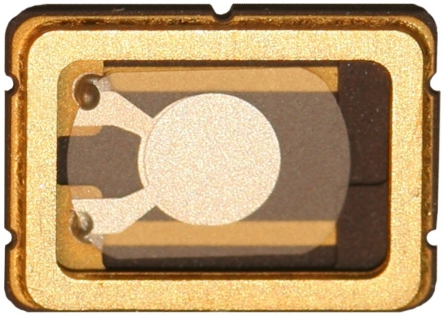
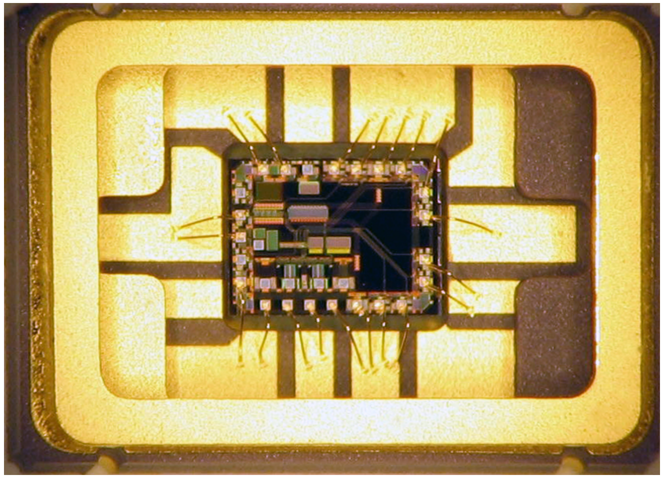
Integration of the Extreme Low Temperature Assembly

Oscillators

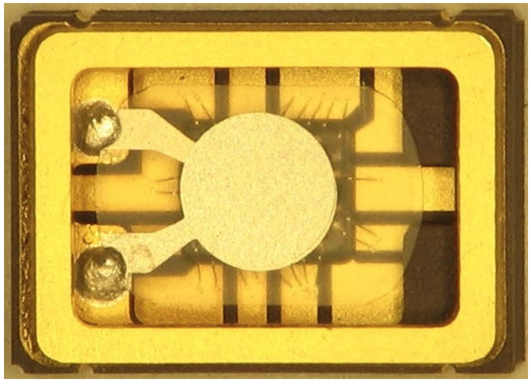
- 5 x 7 ceramic SMD from 500 KHz to 50 MHz
- Packages developed for alternative ICs required for different temp range, and radiation tolerance
- Single IC solution → higher reliability





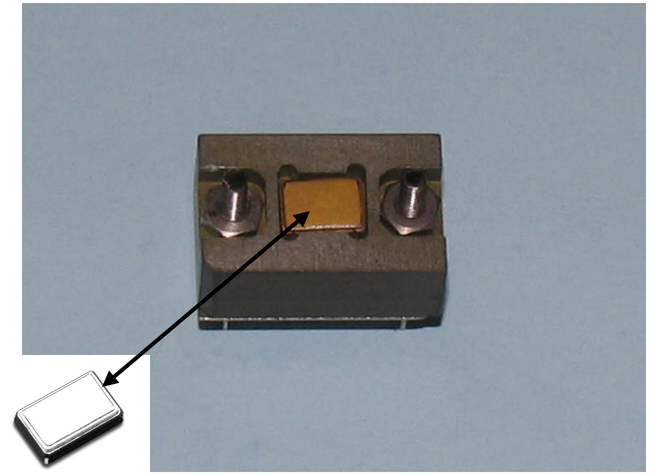
Crystal resonator

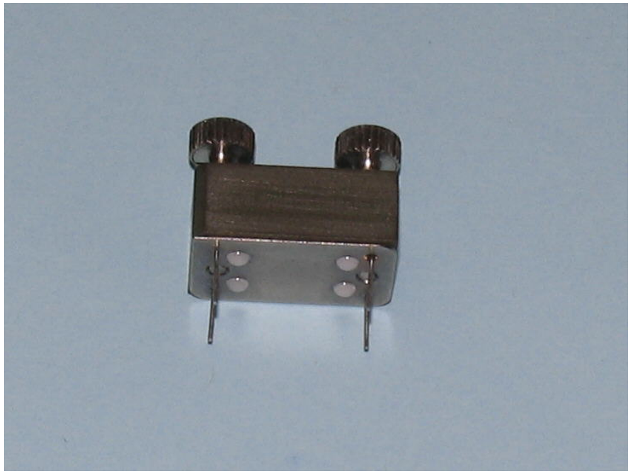
- 5x7mm SMD from 8 to 110 MHz single rotation
- Double rotation cuts in testing stage
- Longitudinal mode elimination by design
- miniature resonators more suitable for random vibration



Testability Provisions

- Developed very rugged test fixtures to handle very large temperature ranges
- Can be used directly or can be used added as an adaptor in an existing test socket and be used on test boards already made for standard DIP packages
- Fixtures will last a long time and will be used in various stages of manufacturing and testing such as final precision frequency adjusting, both interim and final electrical testing, as well as burn-in





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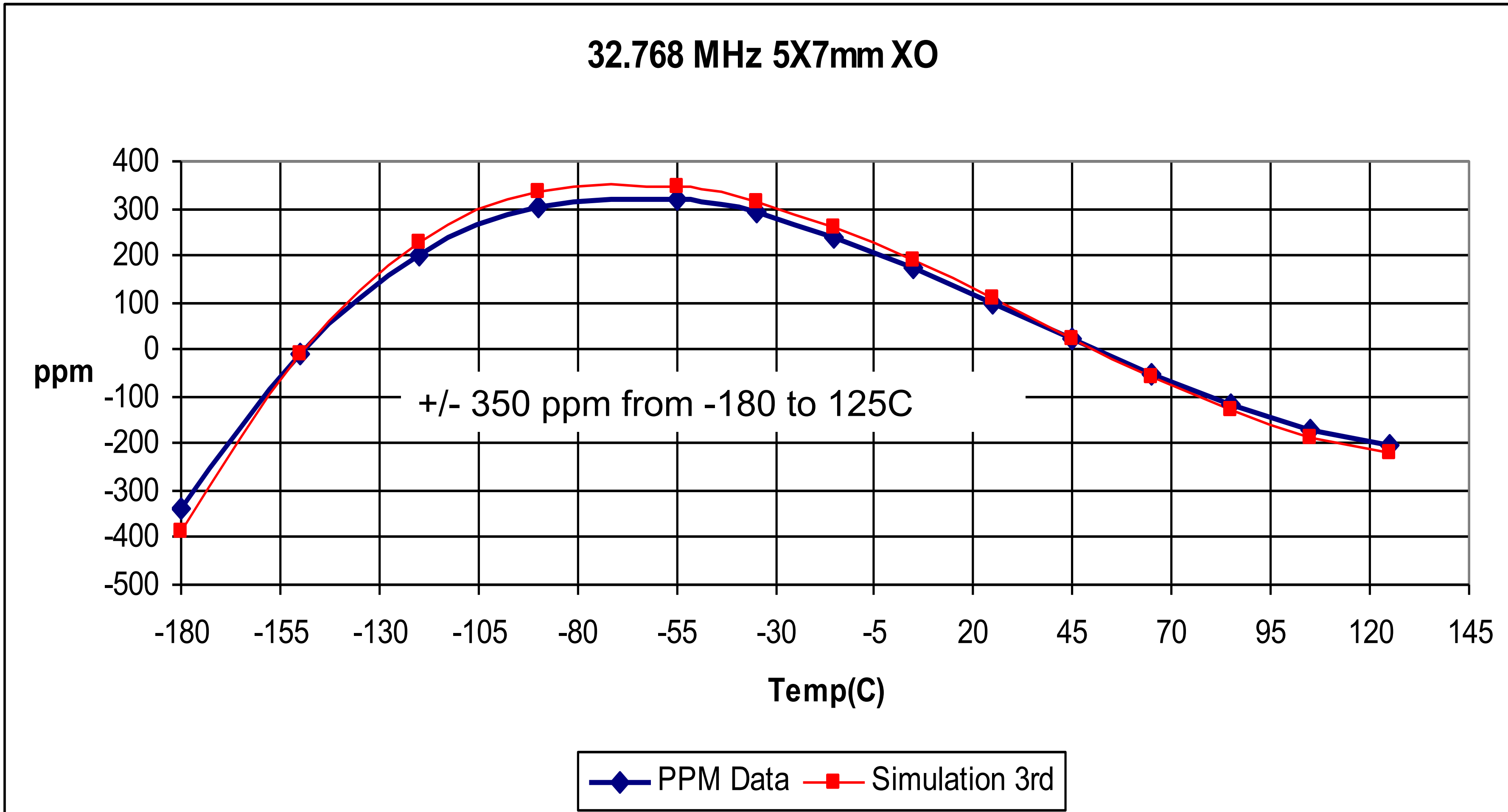
Extreme Low Temperature Frequency Stability Data



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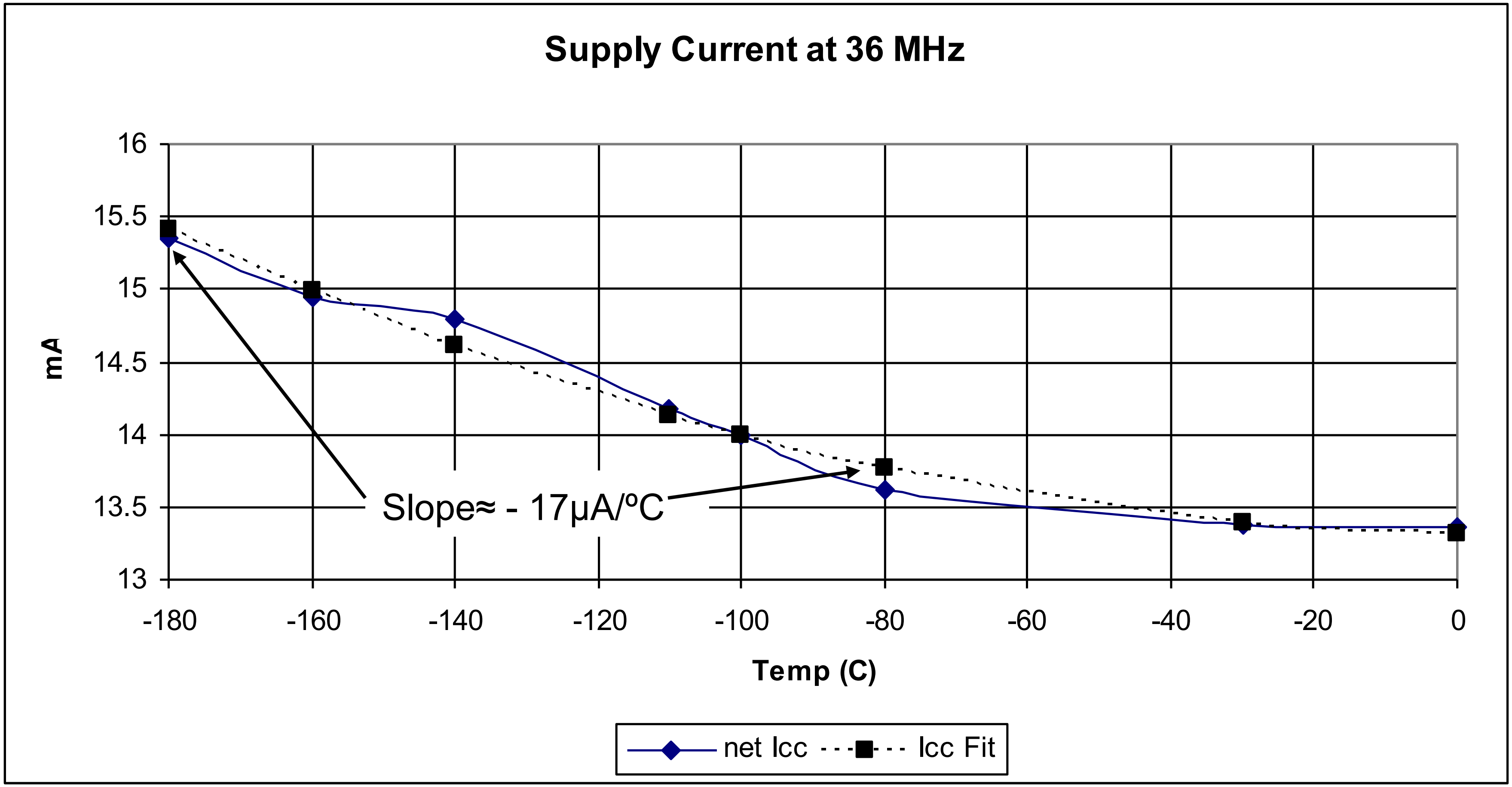
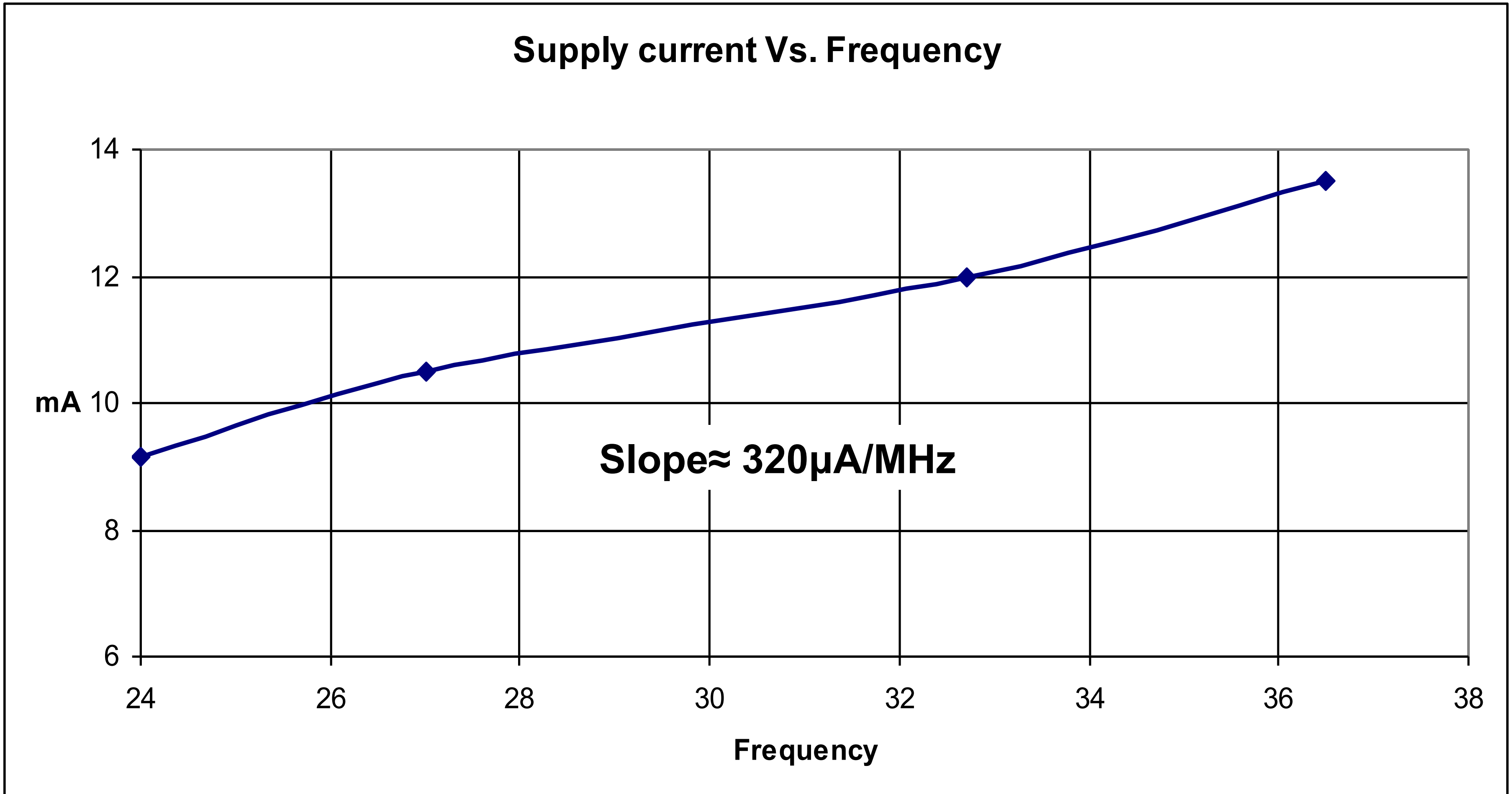
Extreme Low Temperature Test Data



Extreme Low Temperature 5X7 SMD

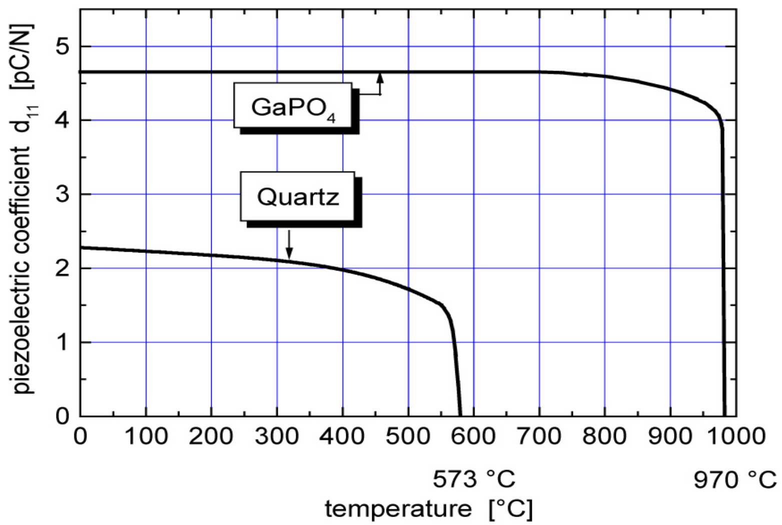


Extreme High Temperature Design Methodology

- Optimized crystal resonator material & cut
- Resonator holder & interconnect provisions
- Extreme high temperature resonator driver circuit
- Electro-mechanical interconnect system
- Material match for substrate & component attachment
- Monometallic bond/welding provisions
- Reinforced packaging to handle 90 bar ambient pressure
- Surface mountable enclosure (preferred)

Extreme High Temperature Design Approach

- **Conventional resonator material**
  - Quartz still performs at T~ 450 C with increasing acoustical loss
  - Phase inversion happens in the low 500C
  - Both single & double rotation crystal cuts were evaluated
  - Double rotation delivers better performance compared to single rotation
  - Results show tolerances in the order of **+**/- 0.5% (-55 to +450)



Quartz Resonator Results

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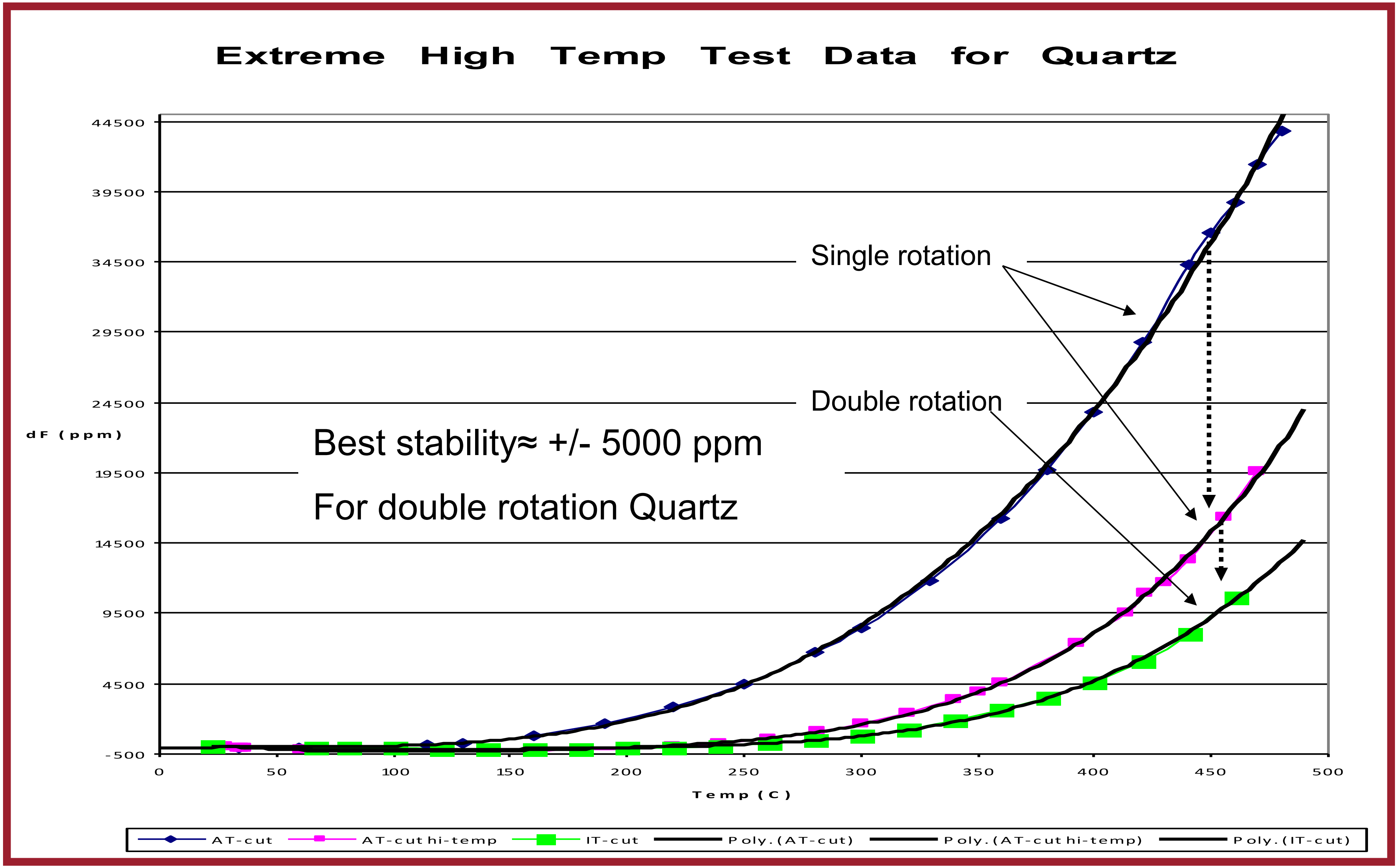

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Extreme High Temperature Design Methodology

- **Non-Quartz resonator material**
  - Optimized Gallium Phosphate resonator as the suitable material
  - Very stable as Piezoelectric material with phase inversion at T > 800ºC
  - Performance over temperature is closer to parabolic with small 3rd order influence in the defined temperature range
  - Frequency stability vs. temperature can be optimized across a wide temperature range but altering the cut angle
  - Higher mechanical coefficient of coupling has the promise of smaller geometries at the same frequency compared to Quartz with larger pulling
  - Electrode configuration has been matched to the operating temperature to reduce surface tension and aging effects
  - Applications that can stand +/- 400 ppm tolerance (-40ºC to +460ºC) can benefit from this design, more than 12 times improvement over Quartz
  - Further optimization will improve the stability to +/- 250~300 ppm depending on the temperature range

Ext High temp Stability Results

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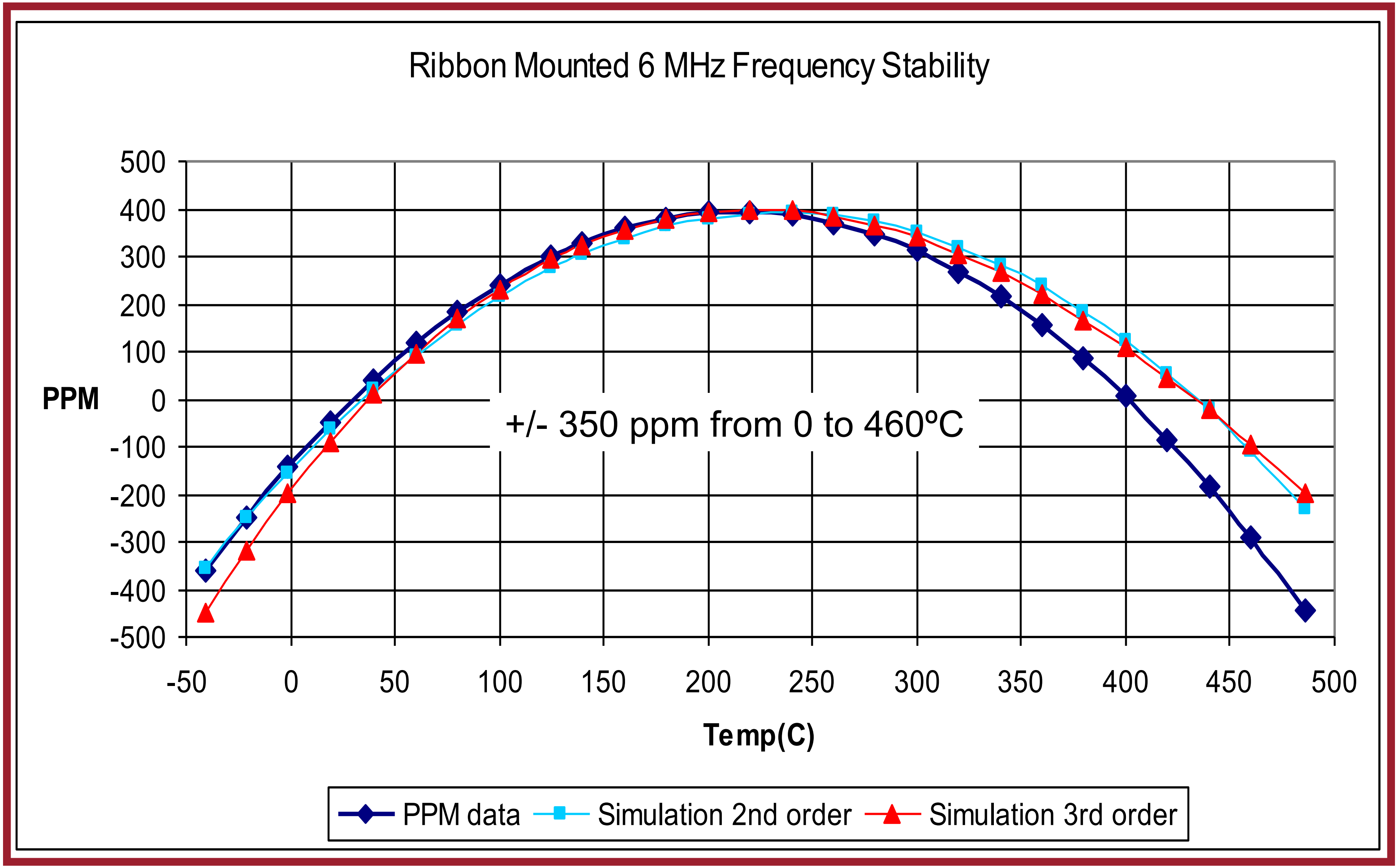

Ext High temp Stability Results

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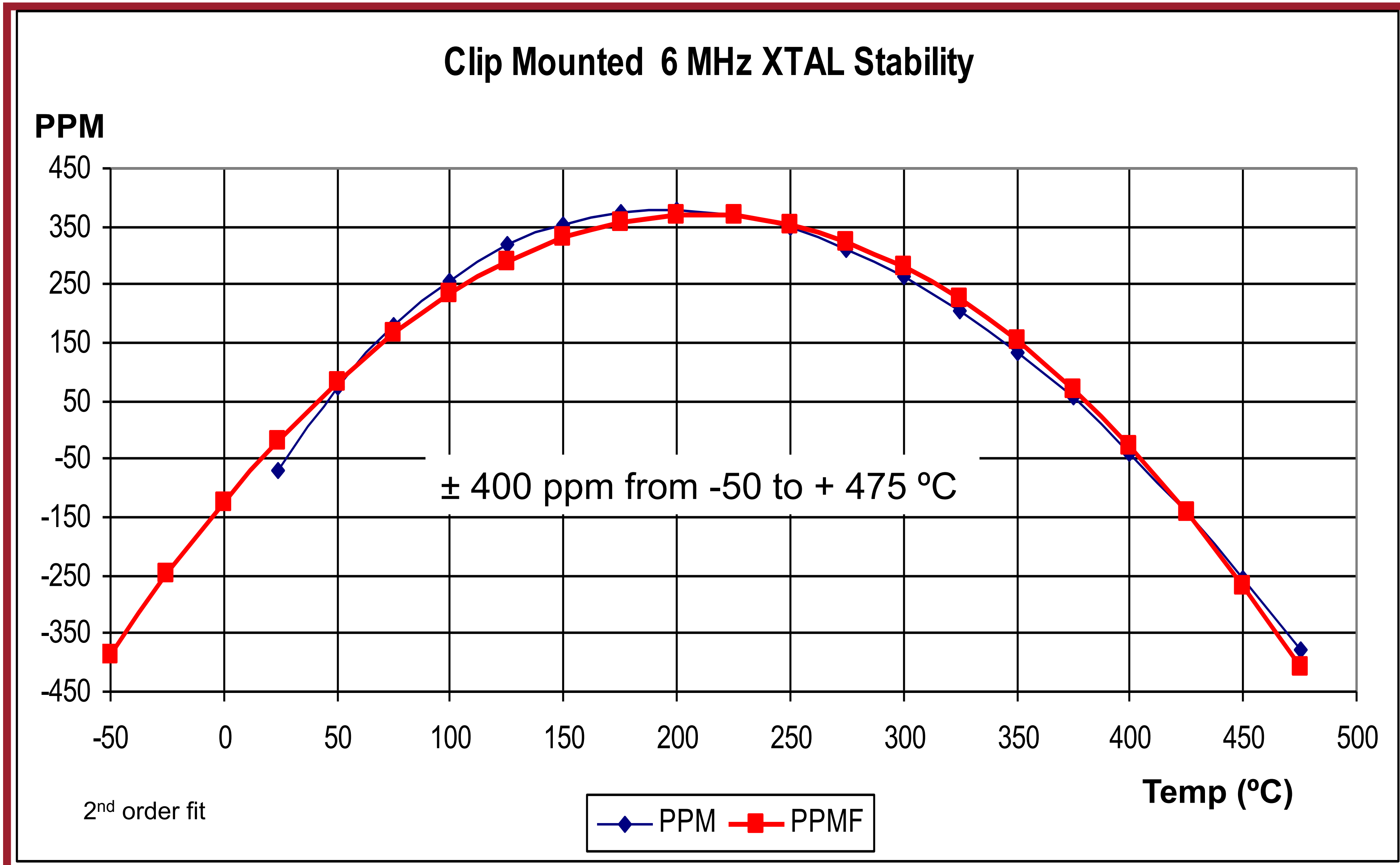

Test to 460ºC & up

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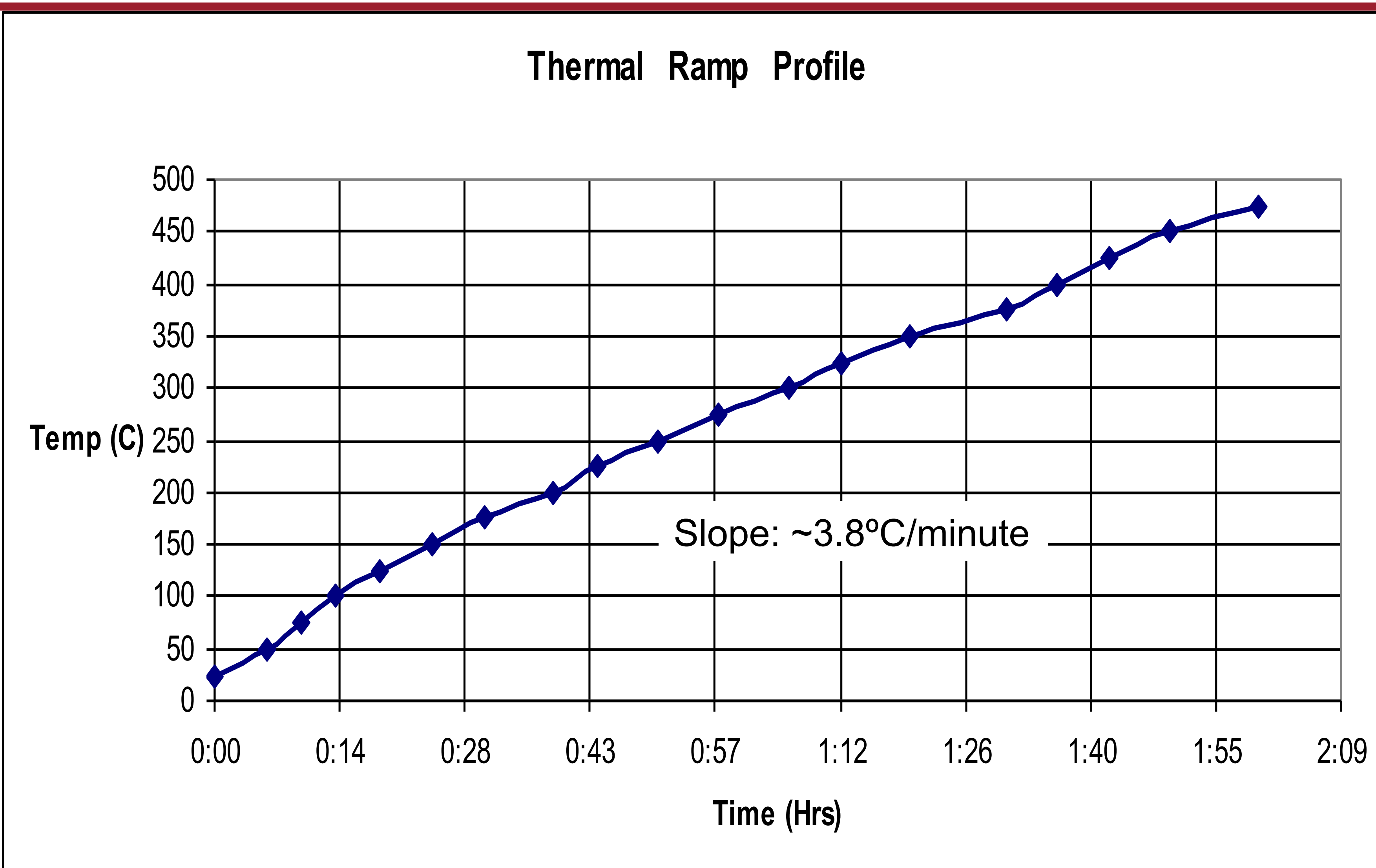

Extended Test @ 460ºC

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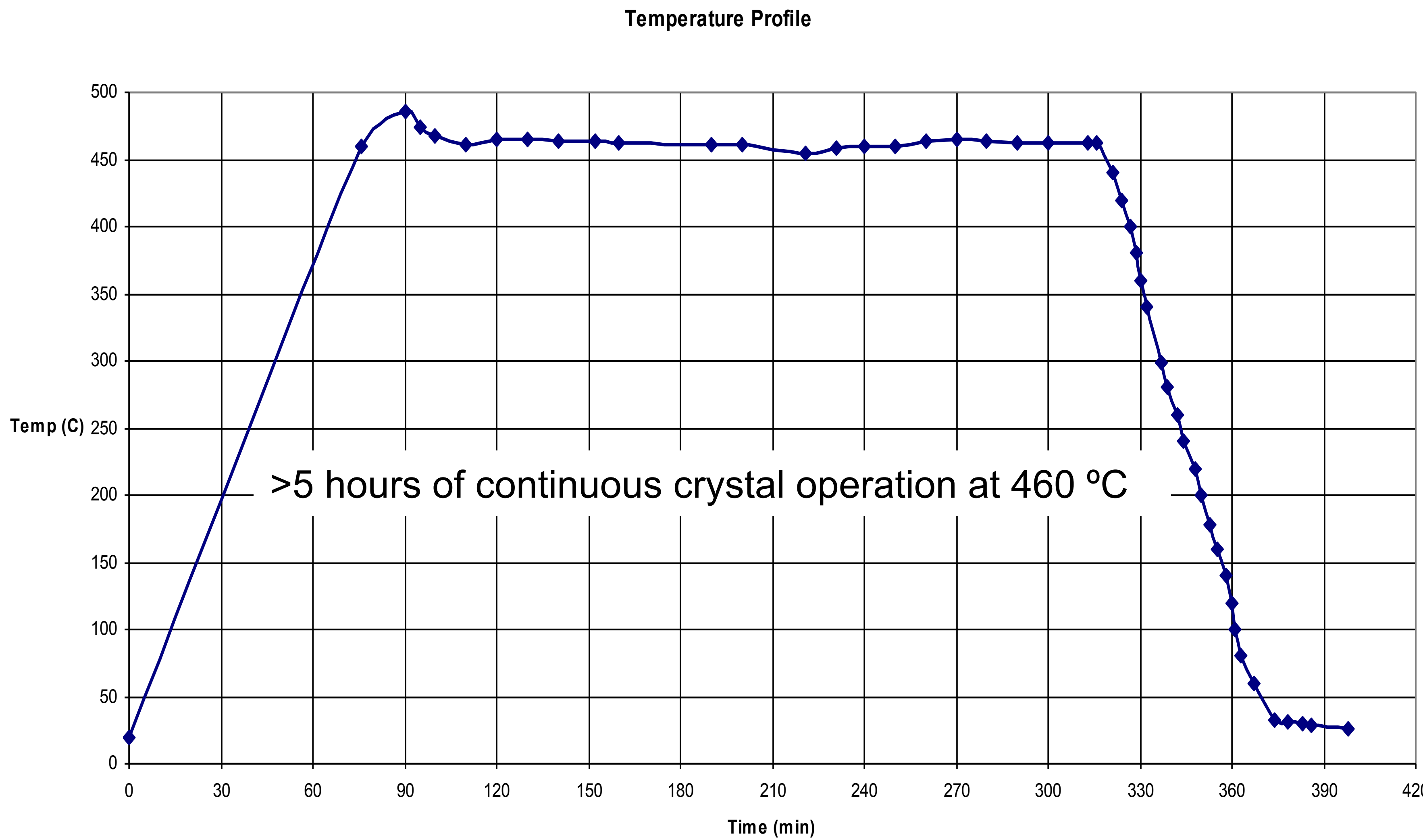
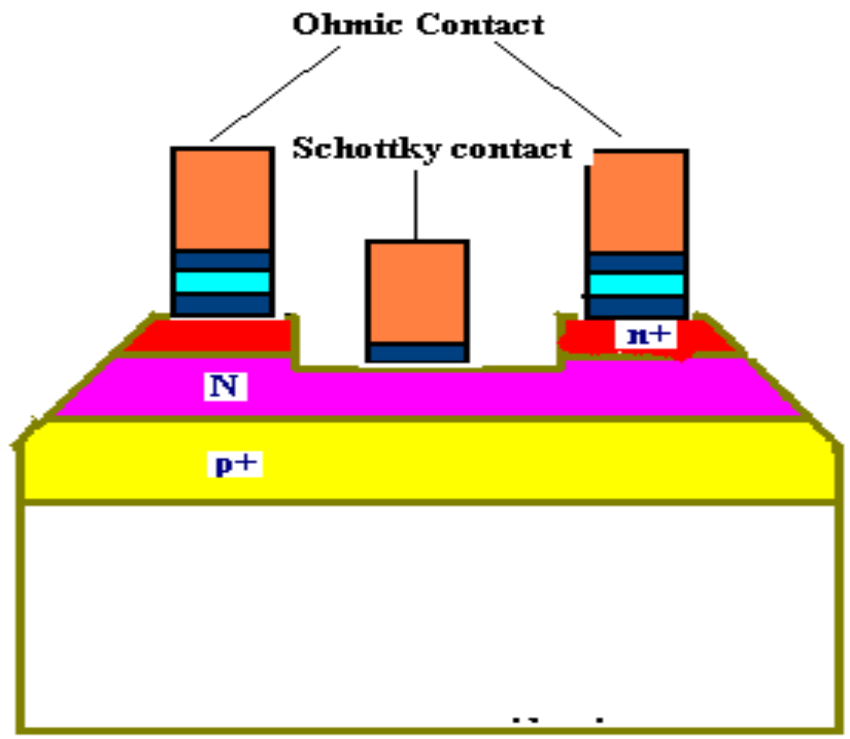


Extreme High Temperature Crystal Driver

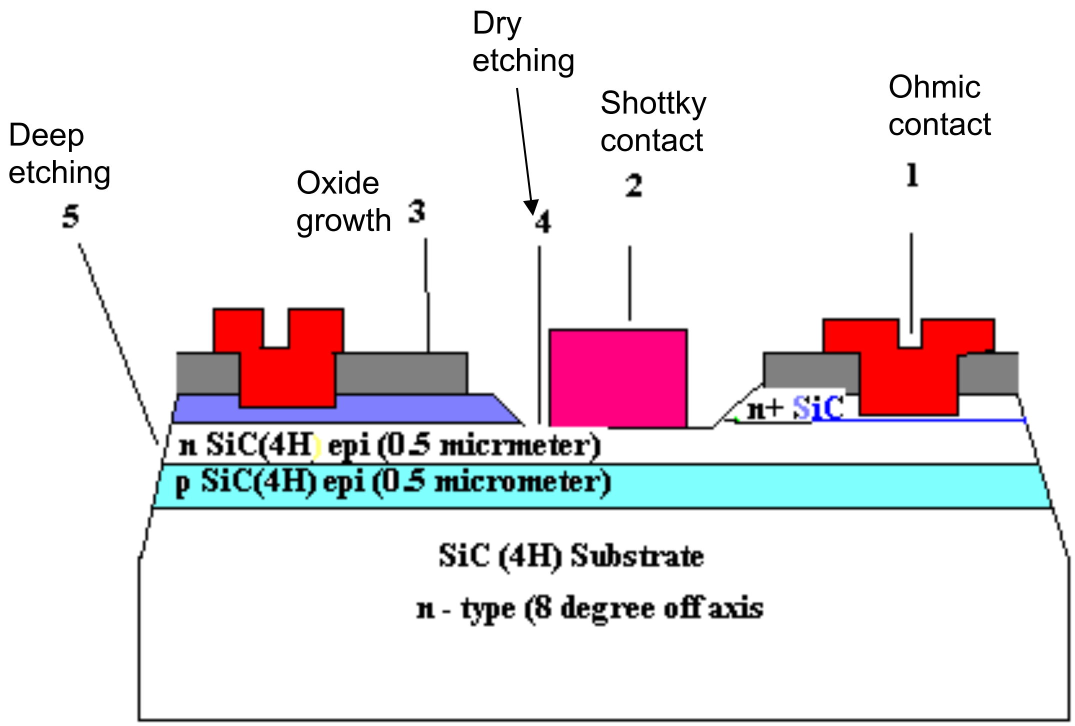
- **Active circuit attributes**
  - Implemented on SiC(4H)
  - Extremely low intrinsic carrier concentration
  - Higher mobility (lateral) among SiC polytypes
  - Ohmic contact
  - Oxide growth process
  - Deep etching process
  - Shottky contact

  Design optimization in progress



Extreme High Temperature Crystal Driver

- **Active circuit attributes**
  - MESFET configuration on SiC(4H)
  - Ti/Ni/Ti ohmic contact process
  - Thermal growth process of SiO2 over SiC
  - Au plated pads will facilitate monometallic wire bonding to the rest of the circuit
  - items1&3 done



Extreme High Temp. SiC Process Optimization

Ohmic Contact layers

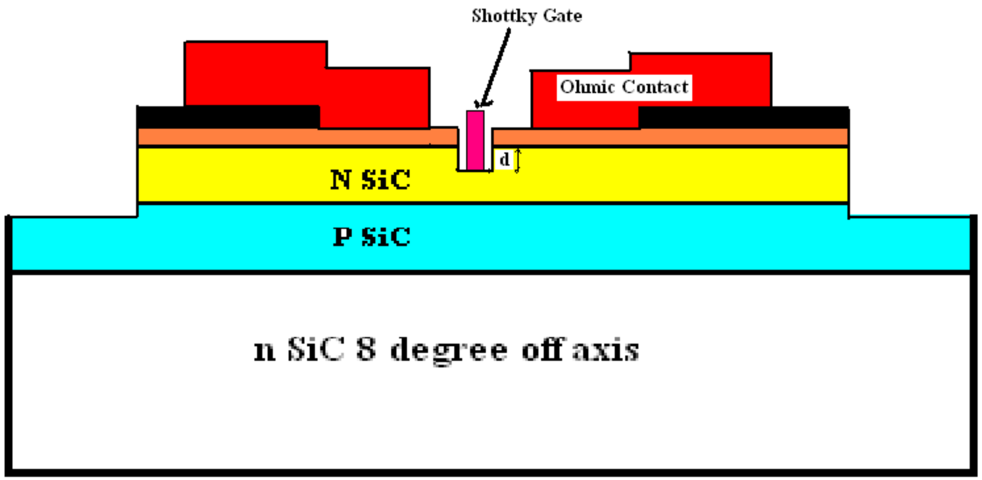
Ti	Ni	Ti	Time/ Temp	Measurement Result
300 A	300 A	100 A	1. 2' at 950 C 2. 2' at 1000 C 3.2' at 1050 C	Ohmic, Rc ~ 180 Ohm Ohmic, Rc ~ 150 Ohm Ohmic, Rc ~ 110 Ohm

Oxidation method for SiO_2 growth over SiC

Oxide Thickness (Å)	Method	Time (Hr)	Temperature (°C)
50 (top layer)	Dry	1	1140
500 (middle)	Wet	3	1140
50 (buried)	Dry	1.25	1140

Extreme High Temperature Crystal Driver

- SiC fabrication process optimization now in progress
- Etching process optimization to control the depth “d”
- First prototype MESFETS are expected by late July



Approximate layer structure

In Summary

- Frequency Management International (**FMI**) specializes in extreme environment and high performance frequency control products used in a wide range of applications
- We now have clear results for extreme low temperature and extreme high temperature crystal oscillator development
- We look forward to contributing to applications that would benefit from our capabilities, technologies and progress
- Our commitment and primary focus is our customers. We strive not only to meet, but to exceed our customers requirements and expectations in order to best support their objectives

Excellence in Extreme Environment Technologies

Manufacturing Facilities & Capabilities

- Main facility in Huntington Beach, California with more than 16000 SF operating space including product specific manufacturing & test equipment, clean room upgrades
- Resonator manufacturing processes such as lap/Polish/contour, base plate, final plate and seal
- Hybrid manufacturing processes such as component attachment and wire bonding (ball and wedge), resonator packaging, resistance and seam welding
- Routine screen testing processes (Stability, aging, Burn-in (extreme temperature), thermal cycling, fine/gross leak testing)
- Tests guidelines per high reliability standards i.e. Mil 883, 202, 55310, etc.
- Outsource other tests to approved test facilities

Manufacturing Facilities & Capabilities

- Process control and documentation as a critical part of QA according to the leading industry certifications
- Wire bonding, epoxy attachment, vacuum deposition, vacuum baking,
  resistant and seam welding, marking, fine and gross leak testing, aging, burn-in, thermal cycling, moisture detection, automated testing (crystals, oscillators, hybrids), IT based automated order status and lot-traveler generation, formatted test data presentation, lead forming
- More than 100 years of engineering experience
- More than 60 years experience in the design & manufacture of crystals and hybrid oscillators